Hydraulics Manual for Fishermen

Hydraulic Power Transmission Maintenance and Troubleshooting

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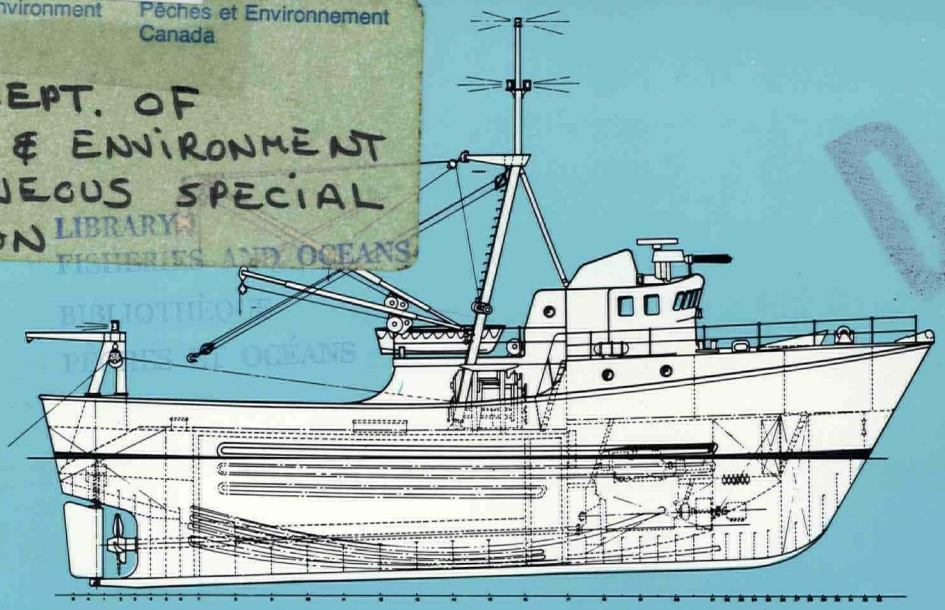

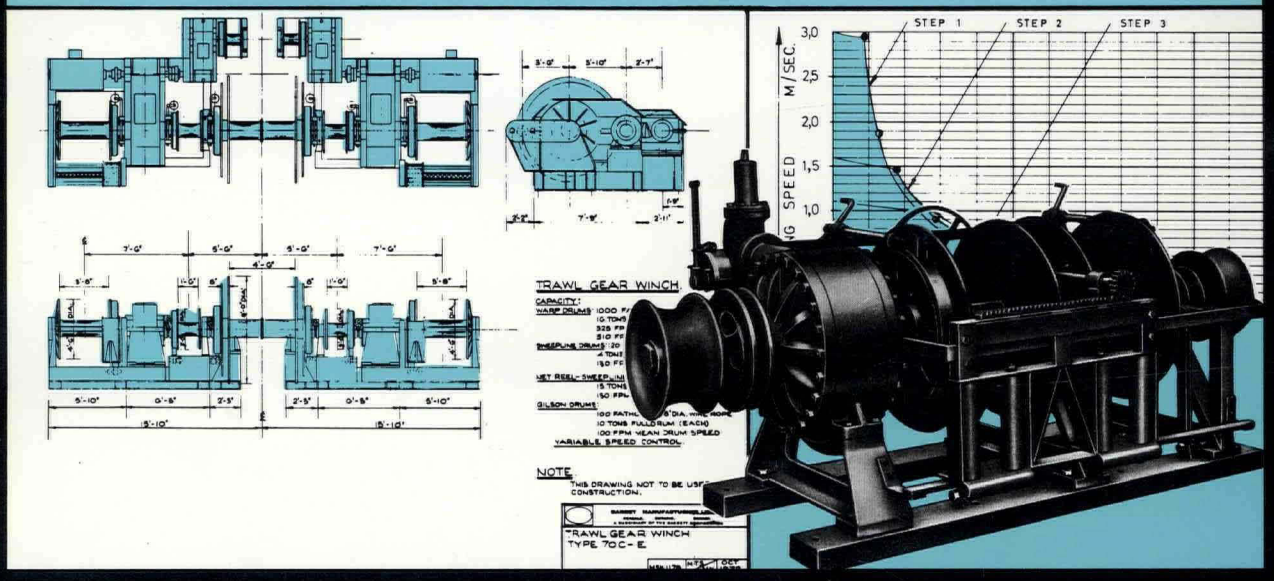

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Hydraulics Manual for Fishermen[1]

Booklet

Hydraulic Power Transmission Maintenance and Troubleshooting

Department of Fisheries and the Environment
Fisheries and Marine Service
Fishermen's Services Branch
Ottawa, Canada K1A 0E6

DEPARTMENT OF FISHERIES AND THE ENVIRONMENT
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FOREWORD

If the fisherman is to achieve a good standard of living he must obtain a good profit from his catch. He has little control over the number of fish available or the demand for his product; his expertise is catching fish. To do this efficiently it is necessary to have good but not necessarily the most expensive equipment. However, the equipment must be safe, efficient, reliable, durable, and economical. Deck machinery helps men handle nets and process fish and this machinery needs a source of power. Because the power must be transmitted, the prime mover and transmission have to be as reliable as the machinery. It is a common opinion that machines and prime movers are reliable but that the weak link is the transmission, particularly when it is hydraulic. There is some justification for this opinion because in the past many mistakes have been made in the design and installation of hydraulic transmissions. However, transmission of power by hydraulics is especially suited to the needs of deck machinery. Properly designed and installed it is safe and dependable, and is good enough for use in large aircraft. But to be successful, a hydraulic transmission must be designed, installed, and maintained by knowledgeable people.

This Manual consists of six separate Booklets. They outline the ideas, materials, and methods used to create a safe, efficient, and reliable hydraulic power transmission. Generally, the discussion of each topic is brief and, no doubt, some points are missed; however, the intention is to help the practical worker understand hydraulics. Although written mainly for mechanics, the Manual should also be of value to system designers and draftsmen because it emphasizes practical requirements. The mechanic must have some knowledge of the principles behind the design of hydraulic power transmissions, appreciate the great need for cleanliness inside the system, and the necessity to keep the operating temperature at a reasonable level. He should understand how the various components work, and how to carry out necessary troubleshooting and repair procedures. Special knowledge and skill are needed by the hydraulic systems mechanic and this Manual will supply some of that knowledge. Skill will be obtained when he applies this knowledge to his work.

Fishermen's Services Branch
Fisheries and Marine Service
Department of Fisheries and the Environment

Maintenance

1. INTRODUCTION

Maintenance is necessary on every mechanical, electric, pneumatic, and hydraulic power transmission system. Maintenance prevents breakdowns and extends the transmission service life. Preventive maintenance reduces component wear by ensuring all moving parts are properly and continuously lubricated. In a hydraulic power transmission, preventive maintenance keeps the system oil in good condition, and the system filled with correct type of oil. To perform satisfactorily a hydraulic system must be kept full of clean oil. To achieve this:

1) Change oil at regular intervals.

2) Prevent leaks by regularly checking that all rigid and flexible piping is properly clamped and supported.

3) Correct leaks immediately without damaging components or permitting contamination to enter system.

4) Keep system reservoir topped-up with clean oil of specified type to prevent oil aeration and overheating.

5) Ensure accumulators in the system are properly charged with nitrogen gas.

2. TRANSMISSION ACCEPTANCE CHECKS

The owner of the ship is responsible for the hydraulic power transmission and the crew must keep the system in good running condition. Before accepting the equipment the owner must know the system has been properly built. Transmission performance tests are normally conducted to the satisfaction of the purchaser before the equipment is accepted. However, the purchaser should also be assured the inside of the transmission is clean, because cleanliness determines reliability. As a precaution, check the reservoir for contamination after performance tests.

2.1 Magnet Check

The magnet check indicates if the system is acceptably clean:

1) Wrap a magnet attached to the end of a rod of suitable length with clean surgical gauze.

2) Remove reservoir lid, or if this is not practical, the oil filler cap.

3) Insert magnet into reservoir and move at random over the bottom and into each corner.

4) Remove magnet and check for visible contamination. If there are more than one or two solid particles, drain and thoroughly clean reservoir.

2.2 Oil Contamination Test Kit

Portable equipment is available for checking solid contaminants in hydraulic oil. One test kit, manufactured by Tyrone Hydraulics, Corinth, Miss., USA gives an accurate, easy-to-read indication of oil contamination.

3. ROUTINE AND PERIODIC MAINTENANCE

Preventive maintenance required by reliable equipment can be classified as routine or periodic maintenance. Routine maintenance is the equivalent of minor checks by gas pump attendants at an automobile service station. Periodic maintenance is the equivalent of work done when oil is changed at a service station.

3.1 Routine Maintenance

This is an inspection process and as minor defects are corrected the mechanic develops a feeling of how the system runs. A mechanic interested in the equipment he services soon recognizes operating noises, temperature, and smell. This knowledge enables him to sense impending trouble and make repairs before it becomes serious. System repairs should not be needed for some time.

3.1.1 Check Oil Level Check the oil level each time the hydraulic system is started. Oil escapes from the system only by external leaks, and regular checks of the oil level, which should be about halfway between the high and low marks on the reservoir indicator, determine if oil is leaking. Never allow oil level to fall below the low mark on the indicator. A low oil level in the reservoir increases the possibility of air being drawn into the pump inlet and this can cause serious damage to the pump.

3.1.1.1 ***Changes of Reservoir Oil Level*** In hydraulic systems with large cylinders and accumulators, oil level in the reservoir may change significantly. When a cylinder rod extends, less oil is returned from the rod end than is pumped into the cap end of the cylinder, and the reservoir oil level necessarily drops. Conversely, when the rod retracts, the reservoir oil level rises again. An accumulator stores oil from the reservoir, and as oil enters the accumulator the reservoir oil level drops, and rises again when the accumulator discharges. When there are cylinders or accumulators in the circuit, check reservoir oil level when all cylinder rods are fully retracted and accumulators are completely discharged. Check again when the cylinder rods are fully extended and the accumulators are fully charged to ensure oil level is still above the low mark on the indicator.

3.1.1.2 ***Water in Reservoir*** Water enters the reservoir by a water-to-oil leak in a shell-and-tube type cooler, and by condensation of water vapor from humid air in the reservoir. A leaking oil cooler increases the level in the reservoir immediately. Condensation increases the level at a much slower rate. A large amount of water in the system gives the oil a milky appearance and seriously reduces the lubricating quality of the oil.

Therefore, if the oil develops a milky appearance, drain the complete system and immediately flush with new oil. See Booklet 5, Section 12.2 for system flushing procedure.

Water entering the reservoir at a slow rate (probably condensation) settles in the bottom of the reservoir because it is heavier than oil, and can be easily detected by occasionally draining a small sample of oil from the bottom of the reservoir into a glass jar. Any significant amount of water can be clearly seen at the bottom of the oil sample. Water thus formed must be drained from the reservoir.

3.1.2 Oil Leaks When a hydraulic system is in service, hydraulic shocks and vibrations from within the system and mechanical shocks and vibrations from outside the system may cause oil leaks. Oil leaks occur most frequently at piping connections, but seals in component casings can fail and oil seals on pump and motor shafts, cylinder rods, and control valve plungers can deteriorate and eventually leak. Watch for oil leaks at any point in the system and repair at the earliest opportunity. Oil leaks can be hazardous to the individual and lost oil is expensive and inconvenient to replace.

3.1.3 Adding Oil to System The following are rules for adding oil to the system:

1) Make sure oil is same type as that already in system. A different oil may not have the required additives, may not mix with original oil, and severe trouble (probably pump failure) can quickly occur.

2) Always add new, clean oil. Do not add used oil and never add oil collected from leaks in the system, because the hydraulic system depends on clean, uncontaminated oil for reliable operation. Used oil is dirty and may have lost some lubricating qualities. Even airborne dust accelerates wear in hydraulic components subject to high pressures. Water in the oil reduces its lubrication qualities and causes rust and wear inside components.

3) Thoroughly clean containers used to transport oil to the reservoir. Clean top of oil storage drum before opening. If a pail and funnel are used, clean thoroughly with diesel fuel or a suitable solvent and wipe dry with clean, lint-free rags. The best method is to pump oil from the storage drum through a 10-micron, full-flow oil filter into the reservoir. A simple transfer pump, hose, and filter are easy to assemble and store and are convenient for adding oil when required.

4) Replace reservoir filler cap.

5) Tightly cap spare oil storage drum and store away from water and dirt.

3.1.4 System Operating Temperature Hydraulic power transmissions are designed to operate with a reservoir oil temperature between 40 and 55°C (100–130°F), other components in the system, such as pump and control valves, usually operate at slightly higher temperatures (approximately 5–10°C (10–20°F) higher). The oil reservoir should have a good quality dial thermometer. Check the reservoir oil temperature regularly and note the normal value. Any significant increase in temperature (say 10°C (20°F)) could be an indication of trouble in the system.

3.1.5 Loose Piping To prevent leaks, protect oil piping joints from shocks, vibration, and unnecessary movement by supporting piping materials properly. Firmly attach steel pipe and tubing runs to a rigid supporting structure with rubber-bushed (or similar material) clamps. These clamps reduce noise transmitted by piping. Often clamps must be used to hold flexible hoses clear of other parts and eliminate undesirable movements. If clamps loosen in service, they become ineffective, and should be tightened immediately.

3.1.6 Flexible Hoses In addition to leaks between the hose and its end fittings, (often indicated by a wet hose cover) watch for signs of abrasion on the cover of hoses. All hoses move under pressure changes and vibration, and if not adequately restrained may rub against other equipment. The outer cover wears away and the exposed reinforcing wire quickly rusts and weakens. A loose hose clamp also causes abrasion, so be sure hoses are adequately clamped. A hose weakens when bent in too small a radius. The hose manufacturer's catalog gives information on minimum allowable bend radius (always have a catalog on hand). Replace at the earliest opportunity any flexible hose assembly that shows signs of deterioration. See Booklet 5, Section 10.5 for flexible hose installation procedure.

3.1.7 Accumulator Nitrogen Precharge Pressure If a hydraulic system contains an accumulator, occasionally check the nitrogen precharge pressure in the following sequence:

1) Be sure pump is not running, and take steps to prevent prime mover from being started.

2) Discharge all oil from accumulator. An accumulator drain cock and line should be fitted in the circuit so precharge pressure can be checked conveniently. If there is no drain cock and line, operate the actuator directional control valve until accumulator is empty. The actuator will move during this process so be sure this movement will cause no trouble.

3) Install a pressure gauge with a range about 1½ times the precharge pressure onto the accumulator gas valve. Open the gas-charging valve and read indicated pressure. When the pressure is read, the temperature of the accumulator should be about the same as normal system operating temperature.

4) If pressure is acceptable, close gas-charging valve tightly and remove pressure gauge.

3.1.7.1 ***Adding Nitrogen*** If the precharge pressure is low (the system designer should indicate the upper and lower precharge pressure limits), add nitrogen in accordance with the rules in Booklet 5, Section 7.3.

3.1.7.2 ***Bleeding the System*** When a low nitrogen precharge pressure is indicated, gas has leaked either through the accumulator gas-charging valve to atmosphere or into the oil system. Gas leaking into the oil accumulates in high points in the piping, so the system must be bled. After the accumulator has been recharged to the correct gas precharge pressure, start the hydraulic system and refill the accumulator with oil. Carefully open air-bleed taps in the high points of the system so any gas, or oil mixed with gas, can bubble out. Be particularly careful when opening air-bleed taps in an accumulator system because if they are completely unscrewed, oil squirts out of the tapping and the flow cannot be stopped until the accumulator is empty. Gas that has leaked into the oil must have passed the accumulator piston or rubber bladder and it is important to check these components at the first opportunity.

3.2 Periodic Maintenance

No matter how carefully the hydraulic system is built and operated, oil gradually becomes contaminated in service. This means that it gradually loses its lubricating qualities, and periodically needs changing. The oil changing operation provides an opportunity to clean up the system. The frequency of oil changes depends mainly on the system loading and its frequency of use. The condition of the oil can only be tested in a laboratory. Oil companies provide this service, but in the past the usual practice has been to follow the recommendations of the transmission supplier. For fishing boat machinery, an oil change and system clean up once each year is reasonable. However, as its price makes it desirable not to change the oil more often than is essential, it is possible an operator would prefer carrying out the procedure only on the recommendation of a laboratory.

3.2.1 Draining Oil First, drain any accumulator in the circuit. Then drain as much oil as possible from the reservoir, piping, and actuators. Draining the reservoir should be straightforward, but if it is not raised clear of the deck, oil must be pumped out with a separate scavenging pump. Loosen joints at low points in the piping to drain as much oil as possible. As cylinders are sometimes awkward to drain, see procedure in Section 11.1. When each section of the system is drained, immediately reconnect piping to keep out dirt and moisture. Check and replace damaged piping and hoses following installation instructions in Booklet 5, Section 10.

3.2.2 Cleaning Reservoir Clean reservoirs with each oil change:

1) When reservoir is empty, remove clean-out panel, suction strainers, magnets, and diffuser. Keep lid sealing gasket in good condition.

2) Inspect inside of reservoir and components that have been removed. (The only permissible contaminant is oil sludge.) There should be no metal or other abrasive contaminants. Evidence of steel, aluminum, or brass particles suggests one or more components are badly worn and the cause must be investigated and corrected. If there are no signs of trouble, clean inside of reservoir thoroughly, then dry with clean, lint-free, preferably white rags.

3) When reservoir is clean, reinstall clean internal components (thread sealant is not required on pipe threads in the reservoir).

4) Fit a good quality gasket on clean-out panel and be sure there are no gaps for oil to leak out or for air to leak in. Air must only enter or leave through the air filter mounted on top of the reservoir.

3.2.3 Changing Filters Filters continuously strain all solid contaminants from oil, and usually there are three types of filters in a hydraulic system: (1) a micronic full-flow oil filter, (2) a pump suction-line strainer, and (3) an air filter.

3.2.3.1 ***Full-Flow Filters*** Very fine full-flow oil filters clean the oil of microscopic particles. Usually these filters have a rating such that any particle bigger than 10 microns is removed. (A human eye can barely see a 40-micron particle.) These very fine filter elements are commonly made from a resin-impregnated paper material, are not cleanable, and must be discarded after use. Inspect the oil filtering element for solid particles before discarding. Steel, aluminum, and brass particles indicate some working components are badly worn and must be immediately found and replaced. If there is no evidence of contamination, clean the filter bowl and fit a new element following the manufacturer's instructions.

3.2.3.2 ***Pump Suction Strainers*** These are wire wound, cleanable filter elements usually fitted inside the reservoir to protect the pump from contaminants (greater than .005 in.) that enter the reservoir.

3.2.3.2.1 *Strainer cleaning procedure* Suction strainers gradually clog and restrict the flow of oil into the pump, and if not cleaned regularly may cause pump failure:

1) Remove and clean (or renew) strainers each time the system oil is changed.

2) Thoroughly wash the strainer in a good solvent. Most solvents are toxic, so observe necessary safety precautions.

3) Blow strainer dry with dry, clean (not wet, unfiltered) air, then replace strainer in system. If installed inside the reservoir, do not put sealant material on pipe threads.

4) If strainer cannot be thoroughly cleaned, install a new element.

3.2.3.3 ***Air Filters*** Because even airborne dirt can harm high-pressure, heavily loaded components, air entering the reservoir must be finely filtered. Air should, therefore, enter the hydraulic system only by the air filter (breather), so there can be no open holes in the reservoir lid. The air filter may be a separate component, but is usually part of the reservoir oil filling cap and this combination is called a filler-breather assembly. The air filter is commonly rated at 40 microns, although 15-micron units are readily available and more desirable. However, any acceptable filter clogs and can cause vacuum conditions in the reservoir. It is therefore necessary to change the air-filter component when the oil is changed.

3.2.4 Filling System With New Oil When the cleaning operations have been completed, fill the system with new, unused oil in accordance with the general rules given in Booklet 5, Sections 11, 13, 14, and 15. Pressure testing and flushing procedures (Booklet 5, Section 12) are not necessary unless the system has been reworked or repaired.

3.2.4.1 ***Oil Specifications*** Use the same type of oil originally installed in the system. This should be an R and O type mineral base hydraulic oil with an antiwear additive. The exact brand should be specified in the system maintenance instructions.

3.2.5 Oil Coolers These components do not require regular servicing. However, sacrificial zinc plugs are often installed in the end caps of shell-and-tube coolers to reduce the rate of tube corrosion. Water in the coolers gradually dissolves the plugs and eventually leaks onto the deck. Replace worn plugs with solid zinc plugs obtainable from the oil cooler supplier. Do not install regular iron or brass plugs as they will seriously reduce the life of the cooler and the hydraulic system.

Troubleshooting

4. NEED FOR TROUBLESHOOTING

All systems break down eventually, and hydraulic systems are no exception. A transmission's design, specification, installation, maintenance, and operation all determine the frequency of repair. This part of Booklet 6, Troubleshooting, deals with possible trouble in a hydraulic transmission and sets out some general rules for the mechanic who is responsible for finding and correcting trouble.

5. DEFINITION OF TROUBLESHOOTING

Troubleshooting (often called corrective maintenance) is an extension of normal maintenance operations (discussed under Maintenance in this Booklet) and is a four-step operation:

1) Find faulty component in a system.
2) Deduce reason for component failure.
3) Repair or replace faulty component.
4) Correct cause of component failure.

6. KNOW THE SYSTEM

Knowledge of the power transmission system is essential to a troubleshooter. An engine mechanic understands engines and their related systems. An electrician understands the principles of electricity and electrical power equipment. The hydraulic power transmission mechanic must thoroughly understand the equipment he maintains, so he can find the trouble and make repairs competently.

6.1 What the Actuator Does

To learn how a transmission works, start at the output end of the system. Forget hydraulics for the moment and understand how the machinery operates. Perhaps a hatch has to be opened and closed, a weight hoisted and lowered, or fishing gear pulled from or set into the water. The machinery is usually simple equipment to lift and lower, or push and pull a load, and the hydraulic actuator is attached to the machinery to make the machinery perform these basic movements. Therefore, the mechanic must know what the actuator is expected to do. Does the actuator push (or pull) the load, or does the load try to runaway? If it runs away the actuator must act as a brake on the load as well as give it motion. The hydraulic actuator has muscle but no brains and cannot tell if the load overruns. The hydraulic circuit is designed to think for the actuator and by studying the circuit the mechanic learns how actuator movement is controlled.

6.2 Hydraulic Circuit

The hydraulic circuit is similar to a map of the system, because it shows the route the oil takes as it

leaves the reservoir, and is directed to the actuator and back to the reservoir. Some valves in the circuit control the direction of oil flow and actuator motion, others limit system pressure, still others control flow rate (gpm) to the actuator. It is necessary to recognize the symbols of various components in a hydraulic circuit. These symbols are simple to understand and are described briefly in Booklet 4, Part I. Working backwards from the actuator through the circuit the mechanic can understand how valves control and direct oil flow to the actuator. In circuits with more than one actuator, investigate one actuator circuit at a time. A valve symbol is usually shown in the valve's normal (deenergized) state, so imagine that each valve has moved to the operating position to allow oil to flow through. The pump is in the circuit only to give the oil a certain flow rate, and it generates pressures needed to overcome loads applied to the actuators by machinery. With one of the more complex, variable displacement pumps, the oil flow rate (and sometimes direction) is controlled by the pump instead of by valves, but fundamentally all pumps are flow regulators and should be thought of as such.

6.3 How Hydraulic Components Work

It is useful to know the operating principles of hydraulic power-transmitting components, particularly when searching for the cause of a system problem. Power-transmitting components (pumps, valves, and actuators) are discussed in Booklet 2.

7. HYDRAULIC SYSTEM FAILURE

In many cases a hydraulic power transmission gives signs of impending trouble, but a sudden failure can also occur without warning, and the system simply fails to operate on command. The cause of a sudden failure may be obvious and the results dramatic, as when a hydraulic line connection or a component bursts. When the cause of failure is not obvious, the trouble must be found before the transmission can be repaired and put back into operation. A hydraulic pump, valve, or actuator may have failed but the trouble could be electrical or something outside the hydraulic circuit. To find and rectify the failure often calls for some detective work.

8. FINDING FAILED COMPONENT

The process of elimination is the logical and best approach. Eliminate from suspicion all parts of the transmission, the drive, and controls that could not have caused the failure. Check the nonhydraulic components. Verify that the prime mover is operational, the pump drive coupling is not damaged, and the machinery is free to move and is not jammed. Operate remote control valves (usually solenoid operated) manually at the valve, to eliminate the possibility of control system failure. When all possible external causes of system failure have been eliminated investigate the hydraulic circuit. Start at each actuator and work back toward the pump to determine whether part or all of the circuit is not operating. If the problem affects only part of the system, narrow the search to components that influence oil flow in that area. Similarly, if the entire circuit is affected, the pump and other components that serve the whole system will be suspect. By working methodically the trouble can be pinpointed in the shortest possible time.

9. SYSTEM REPAIR

The machinery should be repaired as quickly as possible, while observing all necessary precautions. The hydraulic circuit must be repaired without introducing additional contamination. The mechanic must find the cause of failure and restore the transmission to as new a condition as possible. If the faulty part is simply replaced, the problem could recur. Conditions may develop in the system that harm components and these conditions have to be corrected before the transmission is reliable. For example, a cylinder rod bearing may fail and cause the rod seals to fail as well, resulting in an oil leak. Replacing the bearing and rod seals stops leakage for a while, but if the bearing failed because the cylinder rod was misaligned with the movement of the load, this must be corrected or the rod will be subjected to the same damaging side loads. The new bearing will then quickly fail and the leak will reappear.

10. CAUSE OF FAILURE

A failed component is not usually the cause of transmission trouble. Often there is a more fundamental cause and the failed component stops working simply because it is the component most affected by some intolerable operating condition. An important part of troubleshooting is to find the real cause of system trouble. It is necessary to:

1) Understand conditions that cannot be tolerated by each transmission component.

2) Find out if any of these conditions exist in the system.

3) Use the process of elimination to deduce which is the most likely cause of failure.

4) Correct the fault by following good hydraulic system installation practice as outlined in Booklet 5.

10.1 Intolerable Operating Conditions

The hydraulic power transmission is only part of the system that transmits power generated in the prime mover and used by machinery. Operating conditions

may cause failure of any part of the system, not just the hydraulic system and components.

10.1.1 Condition of Nonhydraulic Components Nonhydraulic parts of a hydraulic power transmission system are the prime mover, power-driven machinery, and nonhydraulic control elements such as mechanical, electrical, and pneumatic devices. Any of these important parts of the power transmission system may fail. For example, the prime mover may not start or the machinery may break down. In the control system, mechanical linkages may break, or pneumatic and electrical supplies may also fail. The hydraulic part of the transmission depends on the proper operation of these external services and if they fail, the whole system fails. If the hydraulic system fails to operate properly, ensure that all external services are in proper working order. This may require the assistance of other tradesmen.

10.1.1.1 ***Solenoids*** Electrical solenoids are widely used for actuating directional control valves because a valve can be switched from one operating position to another by means of a solenoid from a control position, which can be situated anywhere in the vessel. Good quality hydraulic valves use industrial grade solenoids of rugged construction, and if properly applied and protected from intolerable operating conditions will not be a source of trouble.

Alternating current (AC) and direct current (DC) solenoids can be obtained to actuate directional control valves. DC solenoids do not shift as quickly as AC solenoids and are even less likely to burn out, but DC power is often not available so AC solenoids are more popular.

10.1.1.1.1 *AC solenoid* When an AC solenoid coil is not energized, the plunger (moving piece that shifts the valve spool) is held away from the iron frame of the solenoid. The moment power is applied high current flows through the coil, the plunger is strongly attracted toward the frame, and rapidly pushes the valve spool to a new position. As the plunger approaches the frame the current in the coil is reduced, so when the plunger reaches the end of travel and seats against the frame, coil current has fallen to a very low level which will not cause overheating problems. The solenoid can continuously withstand temperatures greater than the boiling point of water, and, if continuously energized, will operate very hot to the touch but will not be in any danger of failing.

10.1.1.1.2 *Solenoid failure* The coil of the solenoid assembly is the part most likely to fail. It will fail if it is subjected to (1) excessively high current (this burns out the coil), (2) high-voltage surges (this breaks down insulation and causes short circuits), (3) liquids (these also break down insulation causing short circuits), or (4) high ambient temperature (this also breaks down insulation).

1) The three main reasons for coil burnout due to *excessively high currents* are as follows: (a) When the plunger cannot close against the solenoid's iron frame the high inrush current continues at a high level instead of decreasing and rapidly increases temperature, causing the coil to burn out in 2 or 3 min. The cause of this in a double solenoid valve is probably that the electrical circuit energizes both solenoids at virtually the same time, and the last solenoid to be energized burns out. It is important to ensure this cannot happen under either normal or abnormal conditions in the electric circuit. This type of failure can also result when there is a low voltage condition; the solenoid then cannot develop enough force to shift the plunger and this allows the high current condition to persist until burnout takes place. In addition, contaminated oil might cause the valve to stick and prevent the solenoid plunger from seating, resulting in the same type of failure. (b) High voltage causes excessive holding current (current that flows when the solenoid is closed) and may burn out the coil. (c) If a solenoid is operated at an electrical power frequency other than that for which it is designed, trouble may occur. A 60-Hertz (Hz) coil operated at 50 Hz tends to overheat. A 50-Hz coil operated at 60 Hz produces reduced force and may be unable to shift the valve. In both cases coil burnout is a distinct possibility.

2) *High-voltage surges* (transients) generated in the electrical supply system may be high enough to break down the insulation and short circuit the coil.

3) Coil insulation may be unsuitable for *immersion in water* and may soften and break down after becoming wet.

4) A solenoid valve situated where there are *high ambient temperatures* runs an increased chance of overheating and coil burnout.

10.1.2 Intolerable Conditions for Hydraulic Components Three general conditions cannot be tolerated by hydraulic components. The first is purely mechanical and is the deficient mounting of components. The second and third are contaminated system oil and hydraulic shock.

10.1.2.1 ***Component Mounting*** Casings of working hydraulic components (pumps, accumulators, valves, and actuators) must not be distorted when mounted. Drive shafts of pumps and motors must be accurately aligned with connected equipment. A hydraulic cylinder must be aligned accurately with the movement of its load to eliminate side loads and rod bending. Rules for the correct mounting of all components are discussed in Booklet 5.

10.1.2.1.1 *Distortion and misalignment* In time, mountings can deflect and holding down bolts loosen. Accidents not related to hydraulics can also damage components. Any movement of a component and any external damage can distort its casings and alignment. Distorted casings and misalignment increase friction between sliding members within the component and this increases wear and both internal and external leakage. Eventually leakage becomes intolerable and prevents the component from operating. Also the component may seize or breakage may occur. The component will fail, but the intolerable operating conditions to which it is subjected will be the cause.

10.1.2.1.2 *Piping materials* Rigid and flexible hydraulic lines must be properly supported and clamped to prevent unnecessary movement and stop vibrations being transmitted to piping joints. Rules for the correct installation of piping materials are presented in Booklet 5. Service conditions and accidents can adversely affect properly installed piping. If improperly clamped steel pipe and tubing flex in service, joints weaken and leaks occur. Movement permitted for flexible hose must be carefully controlled. The outer cover of an inadequately supported and clamped hose wears away if it rubs against other components. It may bend into too tight a radius or flex and sag too much. All these conditions overstress the hose and place extra and unacceptable strain on the hose connectors, and this can cause leaks. The piping therefore fails, not because it is unsuitable, but because it has to work under conditions that are intolerable.

10.1.2.2 ***Intolerable Oil Conditions*** Oil in a hydraulic power transmission system must be clean, have a suitable viscosity, and contain the proper additives. It must not contain air or gas bubbles or water. When the transmission was installed, efforts should have been made to ensure there were no solid contaminants or water in it and that it was filled with new, clean, filtered oil. All air pockets trapped in the system should have been released. These precautions are necessary to ensure the system is filled with an oil that not only can operate at the pressures and temperatures of normal service, but also provide the best possible lubrication of components. Solid, liquid, and gas contaminants reduce the oil's lubrication properties and increase the rate of component wear with the result that internal running clearances increase, causing excessive leakage or seizure. The component fails because of unsuitable oil.

10.1.2.2.1 *Cause of intolerable oil conditions* Clean oil in the transmission gradually deteriorates for a number of reasons (discussed in Booklet 3). Even in a well-engineered and installed system, lubrication of components is not likely to be perfect under all conditions and some wear takes place. Contaminant particles are caught in the circuit filter and this prevents them from doing further damage, but oil continuously passes through the filters at temperatures above 38°C (100°F), and fine metal particles trapped in the filter slowly react chemically with the oil to create sludge and varnish. If the concentration of these contaminants increases sufficiently, they can clog clearances and impair lubrication, cause valves to stick, and plug component control orifices. Water seriously impairs the lubricating qualities of oil and reacts with it to form acids that corrode components and create further solid contamination. Air bubbles also seriously impair lubrication in a system and affect the quality of oil. In hydraulic systems where these destructive conditions are controlled, oil deteriorates slowly, but if any condition is out of control, oil breaks down at a much faster rate. Then there is a great increase in frictional losses, oil temperature increases, component wear rates increase, and system contamination increases. Soon the components cannot tolerate the additional oil contaminants. An intolerable operating condition has been created and the component most affected fails first.

The most obvious place for air to enter the oil is in the reservoir because the reservoir is the only place in the system where oil is in direct contact with air. However, if the reservoir is designed and installed to prevent turbulence in the oil and if the correct oil level is maintained, air is not absorbed. Air can be drawn into the oil at any point where a vacuum exists and this often occurs in the pump inlet (suction) line. If properly made, the line will be short, straight, and large in diameter to minimize the vacuum condition. Air sucked into oil causes the oil to foam and possibly bubble out of the reservoir air filter. Under vacuum conditions in the pump inlet port, air can be drawn through a faulty pump shaft seal. The other likely place for vacuum pressures is at the inlet port of an actuator that handles an overrunning load. The actuator acts as a pump, and if the load drives the pump too fast (propably because of a maladjusted counterbalance system) air can be drawn in through the actuator shaft seal. This condition is most likely to occur in cylinder actuators. A motor actuator is usually supplied with an external case drain that reduces, but does not eliminate, the possibility of air entering the system.

A unidirectional motor is internally drained but is not normally employed in overrunning load circuits because the motor casing and shaft seal would be pressurized during the overrunning condition.

Damaging amounts of water are most likely to enter the oil by a leak in the shell-and-tube oil cooler (if one is fitted), but can also enter as airborne moisture (humidity), or as a result of an accident. Water tends to give oil a milky appearance, and if this is noted drain the oil immediately.

10.1.2.3 ***Hydraulic Shock*** A hydraulic system is designed to operate at pressures up to a reasonable maximum level, usually controlled by the pump relief valve setting. Hydraulic shocks can cause instantaneous peak pressures of several times the expected maximum value. These shock pressures occur and die out so quickly they cannot be read on a regular pressure gauge and are the hydraulic equivalent of water hammer. When hydraulic shocks occur, the components are pressurized far in excess of rated pressure, are subjected to an intolerable operating condition, and quickly develop serious leaks or may burst.

10.1.2.3.1 *Hydraulic shock occurrence* Hydraulic shocks are most likely to occur in systems with a large capacity for storing energy — in accumulators for example. Accumulators store energy in oil under a nitrogen gas pressure loading. Circuits that contain long tubing runs, particularly with trapped air pockets, and circuits with a great deal of flexible hose are also susceptible to hydraulic shock, because they have a tendency to trap air. Flexible hose expands when pressurized and acts like a spring on the oil. In any of these conditions, if a control valve is opened or closed rapidly, a pressure wave travels at the speed of sound through the oil. When this wave is reflected at the end of a line the shock raises the pressure to a very high level and creates a condition that the components may not withstand. Directional control valves operated directly by electrical AC solenoids shift rapidly, the shifting speed cannot be reduced, and this often causes hydraulic shock. Better control of shifting speed can be obtained with pilot-operated solenoid controlled valves. Best control can be obtained with a manually operated valve although, if shifted violently, damaging shock pressures can still be generated in the system. Hydraulic shock is difficult to control. The best procedure is to slow down the speed at which directional valves shift. Alternatively, accumulators may be used to absorb the shock, but these must be used with caution as they can also be a source of hydraulic shocks. Ask the hydraulic system supplier for advice on solving hydraulic shock problems.

10.2 Clues to Cause of Failure

Start looking for clues to system failure at the failed component. The trouble may be quickly spotted as the component is dismantled. An easily corrected hydraulic fault could be a control valve orifice plugged with a small piece of Teflon® tape or a rubber chip from a poorly made hose assembly. This causes a pilot-operated relief valve to open at low pressure and a pilot-operated pressure reducing valve to close completely. These soft but solid contaminants are not likely to do serious harm to components, and when removed the component can be carefully rebuilt and the system put back into service. If large or many particles are found during the disassembly process, establish whether they are part of the failed component or are from another component upstream in the circuit. If contamination originated elsewhere, proceed around the circuit against the direction of oil flow inspecting each component until the source of solid contamination is found. The source of contamination is unlikely to be the real cause of the trouble and a further search will be necessary to determine why the solid contamination was produced.

10.2.1 Intolerable Operating Conditions Affect Hydraulic Components Mechanical problems (distortion and misalignment) due to the mounting of components affect all components equally. Hydraulic shocks can also damage any component. All components are susceptible to the effects of contaminated oil and may fail. However, the pump is the most severely loaded component in the system and is, therefore, more sensitive to the combined effects of contamination than either valves or actuators, and is likely to fail first. If there is rapid wear in the pump the entire hydraulic circuit can become contaminated with abrasive, metal particles.

10.2.2 Effect of Contaminated Oil on Pump The three types of contaminants in hydraulic oil are solid, liquid, and gaseous. Solid contamination cannot be tolerated by any power-transmitting component (pumps, valves, actuators). Liquid contamination is usually water in the oil, although it could be unsuitable oil in the system. This contamination affects all components equally, but gaseous contaminants affect the pump more than other components. Air and oil vapor bubbles only exist in harmful quantities at low pressure (under vacuum conditions), and because the pump is charged with oil at low pressure it is easily contaminated by air and vapor from the suction line. When the pump pressurizes oil, the bubbles collapse so violently and generate such high temperature that pump parts are eroded. The released metal particles damage the pump before entering the circuit to cause more trouble elsewhere. The pump failure chain can now be clearly imagined. Oil may be completely clean and free of water but any air and vapor bubbles at the pump inlet will collapse and generate abrasive contamination. This causes increased wear of sliding parts and this in turn increases internal leakage. Internal leakage generates heat, oil thins out, lubrication is impaired, and more wear takes place. These destructive effects, once started, cannot be stopped until the pump is repaired or replaced and the condition that permits gaseous contamination to occur has been corrected. During overrunning load conditions the actuator is converted into a pump and if vacuum conditions occur at the inlet port, failure

of the actuator (particularly a motor) may be initiated. In closed-circuit, trawl winch systems, the transmission is in an overrunning condition during the time the warps are being paid out. The hydraulic motor becomes the pump and if the boosted inlet pressure drops too low, aeration starts the failure chain.

10.2.3 Pump May Indicate Cause of Failure Failure of the pump or any other component is not always due to gas bubbles at the pump inlet. The reason for failure may be obvious but often is not, and there are several possible alternatives. If contaminated oil is suspected as a cause of any component failure, the pump is likely to carry the scars of the contamination. Scars will differ with different types of contamination, and if properly interpreted may indicate the real cause of failure. Some pump manufacturers (such as Tyrone Hydraulics, Corinth, Miss., USA) have published information on the effects of different types of contamination on their pumps and this often helps the mechanic track down the cause of failure. In addition, a knowledgeable inspection of a failed pump or other component, away from the site of failure, may permit the mechanic to determine the cause and the customer can be advised how to prevent similar failures. Pump inspection may indicate system failure is caused by the following:

1) *Abrasive contamination* — If abrasive contaminants have caused system failure: (a) Check that filters are not plugged or too coarse causing poor filtration. Oil filters should be 10-micron, full-flow type. The air-breather filter should not be rated larger than 40 microns. Be sure air cannot enter the reservoir through a badly fitting lid. (b) Check worn cylinder rod scrapers for fine particles of dirt.

2) *Erosion of pump parts* — Erosion inside the pump (even of parts of hardened steel) is caused by aeration (air bubbles) and cavitation (vapor bubbles) in the oil and results from high vacuum conditions at the pump inlet. Check the following possibilities: (a) Pump inlet is blocked by a piece of rag, plastic, or other foreign body. (b) Suction strainer is plugged. (c) Hose liner collapsed under vacuum conditions where suction line contains flexible hose. Only SAE 100R4 hose is suitable for vacuum pressure. High-pressure hose is not suitable. (d) Reservoir oil level is not well above the end of pump suction line. (e) Air-breather filter blocked. If so, air cannot enter and a vacuum will result inside reservoir. (f) Reservoir is not high enough. Poor suction conditions may result if the pump has to lift the oil more than approximately 12 in. into the inlet. (g) Suction line is not short, straight, and as large as possible.

A long suction line containing sharp bends can cause a high vacuum at the pump suction. A suction line should be designed to allow oil to enter the pump at the highest possible pressure (as low a vacuum as possible) because the higher the vacuum the greater the chances of trouble.

3) *Troubleshooting guide charts* — Troubleshooting guide charts (as shown in Table 1) briefly describe various evidence of component failure, and can often be obtained from component manufacturers. A typical chart illustrates the following: (a) The system must have a reason for failing. (b) The failed component is not usually the cause of system failure — there is likely a more fundamental reason. (c) A component failure is probably caused by intolerable operating conditions not initiated by the component. (d) Most common cause of component failure is contaminated oil. (e) Another cause is negligence by installation or maintenance personnel. (f) Most trouble in a system starts because a high vacuum in the pump suction line causes air or vapor to enter the pump.

11. CORRECTING SYSTEM FAULTS

When the fundamental cause of system failure has been found, correct it according to the rules for hydraulic power transmission installation in Booklet 5. If a system is seriously contaminated, flush out the oil completely and replace with new, clean oil because all contamination must be removed. Use the following procedure when cleaning a system after failure.

11.1 Recommended Cleaning and Testing Procedure

The procedure outlined below is based on recommendations of a leading hydraulic pump and motor manufacturer:

1) Fully retract all cylinder rods. It may be advisable to support the load safely and disconnect rod from the load before retracting cylinder rod.

2) Carefully discharge all oil from accumulators in system.

3) Drain system reservoir and as much piping as possible.

4) Thoroughly clean out reservoir. If available, use a high-pressure jet of diesel fuel, but always wipe reservoir clean and dry with clean, lint-free rags.

5) Remove oil filter elements and thoroughly clean out filter bowl.

6) Fit new filter elements of correct type, with a 10-micron rating.

7) Install new pumps according to manufacturer's instructions and follow good hydraulic component installation practice.

8) Fill reservoir with new, clean oil of correct type as specified by hydraulic system supplier (a recognized R & O hydraulic oil with an antiwear additive included).

9) Safely support all actuator loads.

10) Disconnect hydraulic lines at ports of each actuator and place open ends in empty oil drum. Drain oil from actuators.

11) Unload pump relief valve, that is reduce pressure setting to a low level.

12) Run pump with control valves in neutral to flush piping with new oil. Do not let oil level fall below low mark of reservoir indicator. Stop pump and fill reservoir as necessary.

13) Carefully operate each actuator directional control valve and flush lines to actuators. Keep reservoir oil level above low mark.

14) Connect a line to cap end of each hydraulic cylinder, leave rod-end ports disconnected.

15) Carefully actuate directional control valve to fully extend each cylinder rod. Clean oil is pumped into cap end and dirty oil flushed from rod end.

16) Connect hydraulic lines to rod end of each cylinder when rod is fully extended.

17) Connect lines to both ports of each hydraulic motor.

18) Cycle cylinders at maximum flow and no load for approximately 1 hour.

19) Drive hydraulic motors at maximum speed and no load for approximately 1 hour (30 min in each direction if bidirectional).

20) Change oil filter elements after flushing is completed.

21) Check oil level in reservoir and add new, clean oil if required to keep well above low mark on indicator.

22) Reset relief valve to specified pressure.

This procedure is a field version of the flushing procedure carried out during the initial installation of the system and if followed, reliable system performance can be expected. If short cuts are taken to speed up the operation, trouble can quickly result. Unless the clean-up is thorough, a repaired system will fail sooner than the first time. High-performance hydraulic pumps, valves, and actuators will not work for long periods on contaminated oil.

TABLE 1. Troubleshooting guide for gear-type hydraulic pumps.

Evidence of pump failure	Possible cause of pump failure	Possible cause of system failure
1 Sandblasted band around pressure plate bores 2 Angle groove on face of pressure plate 3 Lube groove enlarged and edges rounded 4 Dull area on shaft at root of tooth 5 Dull finish on shaft in bearing area 6 Sandblasted gear bore in housing	1 Abrasive wear by fine dirt particles (contaminants not visible to eye)	1 Dirty oil 2 Incorrect filter element change period 3 Incorrect filter elements 4 Cylinder rod wiper seals in poor condition 5 Cylinder rods dented or scored 6 System not flushed properly after previous failure
1 Scored pressure plates 2 Scored shafts 3 Scored gear bore	2 Abrasive wear by coarse metal particles (contaminants visible to eye)	1 System not flushed properly after previous failure 2 Contaminants generated elsewhere in hydraulic system 3 Contaminants generated by wearing pump components
1 External damage to pump 2 Damage on rear of drive gear and rear pressure plate only	3 Incorrect installation	1 Shaft did not bottom in mating part 2 Interference between pump and machine
1 Eroded pump housing 2 Eroded pressure plates	4 Aeration–cavitation restricted oil flow to pump inlet or aerated oil)	1 Incorrect tank oil level 2 Restriction in pump inlet line 3 Air leak in pump inlet line
1 Heavy wear on pressure plate 2 Heavy wear on end of gear	5 Lack of oil	1 Incorrect oil level 2 Oil returning above oil level
1 Inlet peened and battered 2 Foreign object in gear teeth	6 Damage by metal object	1 Metal object left in system during assembly 2 Metal generated by another failure in system
1 Pressure plate black 2 O rings and seals brittle 3 Gear and journals black	7 Excessive heat	1 Valve stuck 2 Relief valve too low

12. CONCLUSION

The Troubleshooting part of this Booklet discusses troubleshooting but does not describe every possible type of hydraulic system failure and remedy. The first failure experienced with a system will very likely show failure symptoms not described. This is a guide to what the hydraulic troubleshooter needs to know and the way to approach the job logically and constructively. At best, troubleshooting is an inconvenience for the operator of a fishing boat; at worst it is lost production and profits. Minimize the amount of troubleshooting necessary. The purchaser should insist that the hydraulic power transmission is designed by knowledgeable and experienced people (not all hydraulic equipment suppliers have this capability), and also insist that the transmission is installed in accordance with hydraulic industry standards and procedure. If the owner uses and maintains the equipment properly troubleshooting may be unnecessary.

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